The Supersymmetric Higgs

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The MSSM Scalar Sector

- First choice for non-SM Higgs searches

2 parameters $\longrightarrow$ Physics of 4 fields

$$(m_A, t_\beta) \qquad\qquad (h^0, H^0, H^\pm, A^0)$$

a generic 2HDM has 7 more parameters…
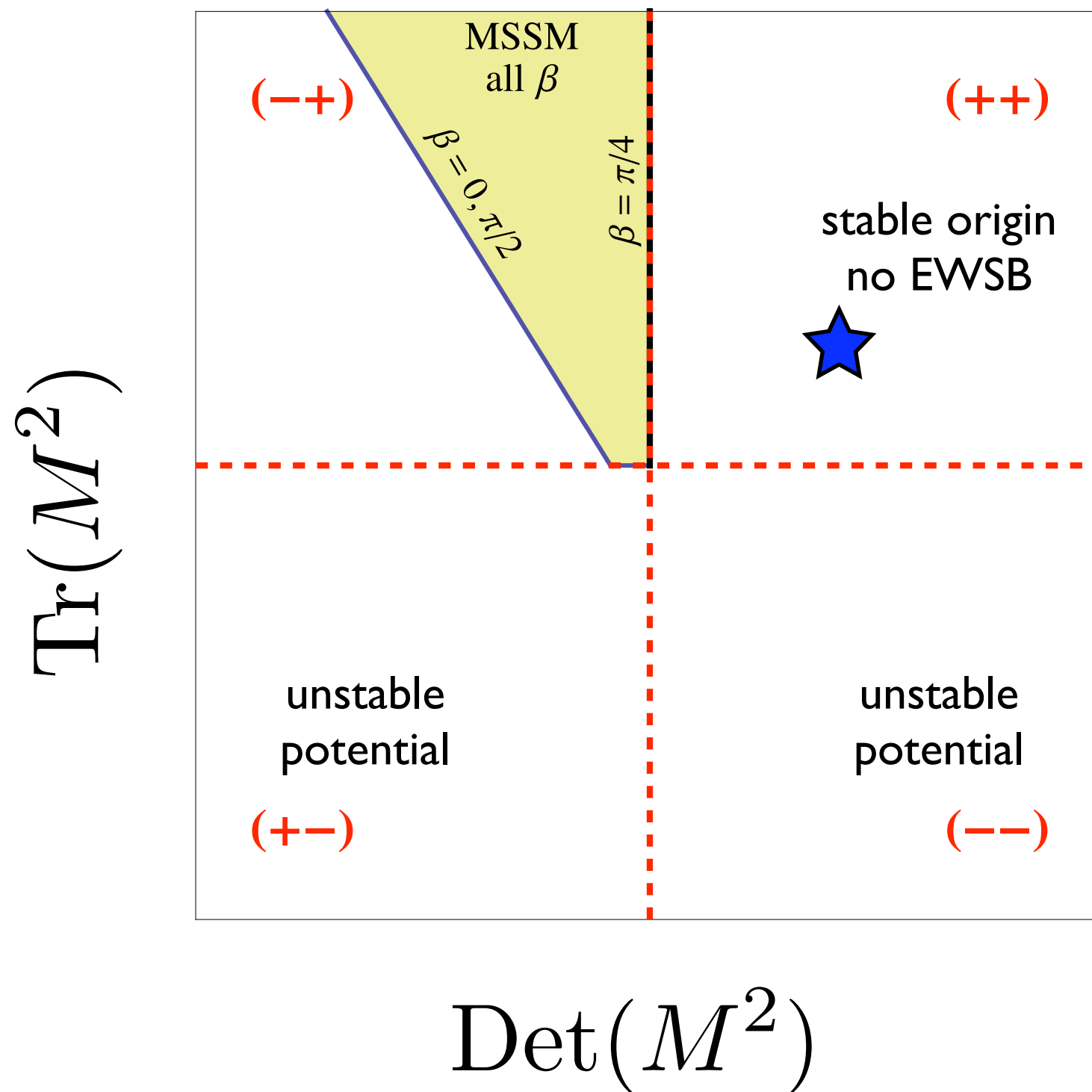
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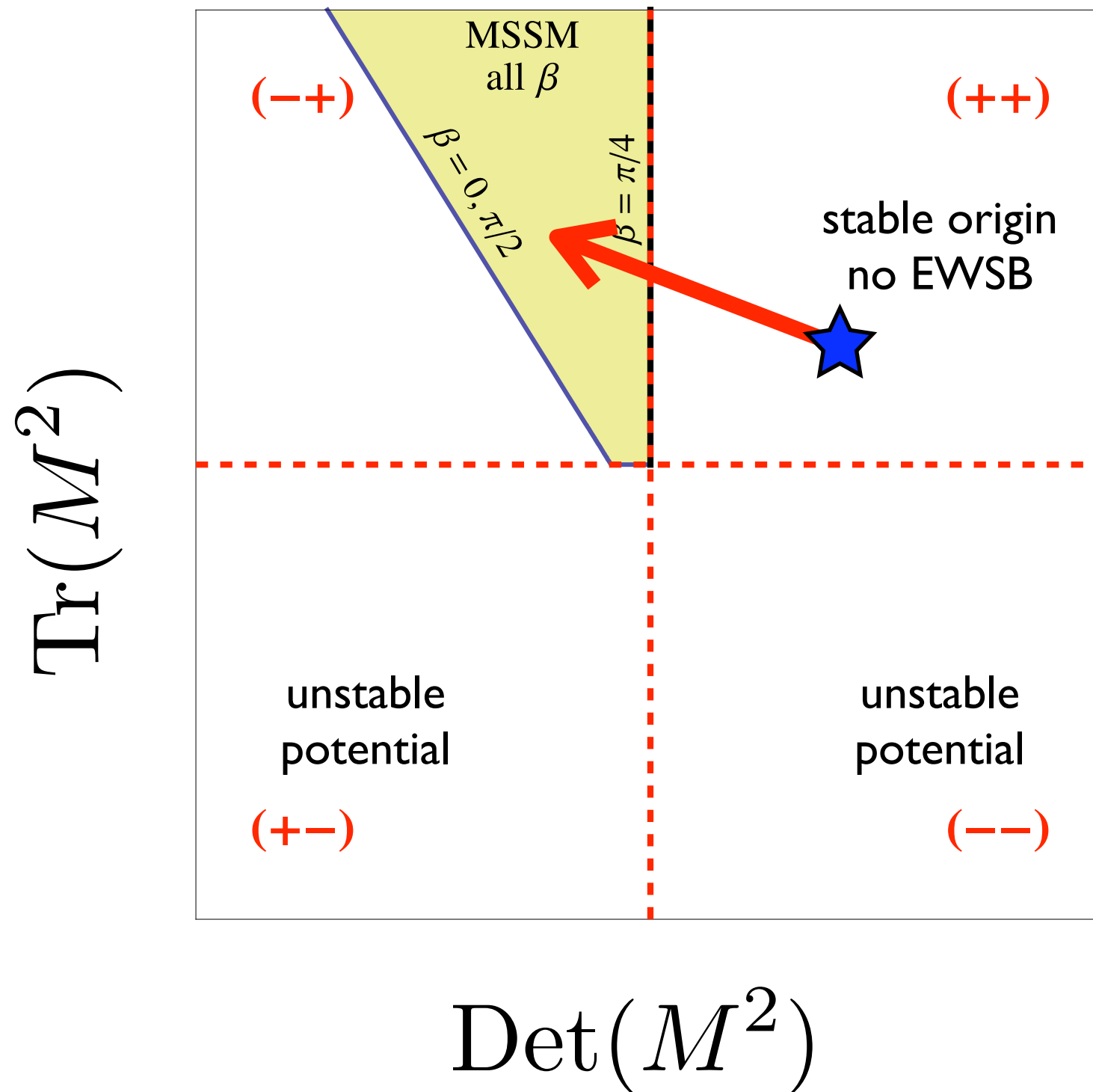
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MSSM all β

$(-+)$

$(++)$

$\beta = 0, \pi/2$

$\beta = \pi/4$

stable origin no EWSB

$\mathrm{Tr} = -\frac{1}{2}M_Z^2 - \frac{2\sec^2(2\beta)}{M_Z^2}\mathrm{Det}$

No EWSB w/o SUSY breaking

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$m_{H_u}^2$ driven negative by top loops

Beyond The MSSM Scalar Sector

- Very Light SM-like Higgs mass

$$m_{h^0} < M_Z \quad \text{at tree-level}$$

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- Can evade LEP bounds via singlet mixing

NMSSM, Dermisek-Gunion, Chang-Fox-Weiner

$$h^0 \longrightarrow 2a \longrightarrow 4b, 4\tau$$

big modifications in the higgs sector! affects collider searches

Outline

- LEP motivates Supersymmetric EWSB (sEWSB)

  SM-like Higgs mass is not directly tied to M_Z
  Another qualitative shift in Higgs physics

- sEWSB captured in an effective field theory

  Only need to consider the MSSM degrees of freedom
  Much easier to identify gross phenomenology (Fat Higgs)

- New paradigm for 2HDM phenomenology

  The heavier higgs, H^0, is naturally SM-like
  The charged Higgs and non-SM-like Higgs are degenerate
  Very rich vacuum structure

Supersymmetric EWSB (sEWSB)

- SUSY-limit of EWSB

Vector Superfield 'eats' a chiral superfield

$$M_{H^\pm} = M_{W^\pm} \quad , \quad M_{h^0} = M_{Z^0}$$

The super-radial mode contains the SM-like Higgs
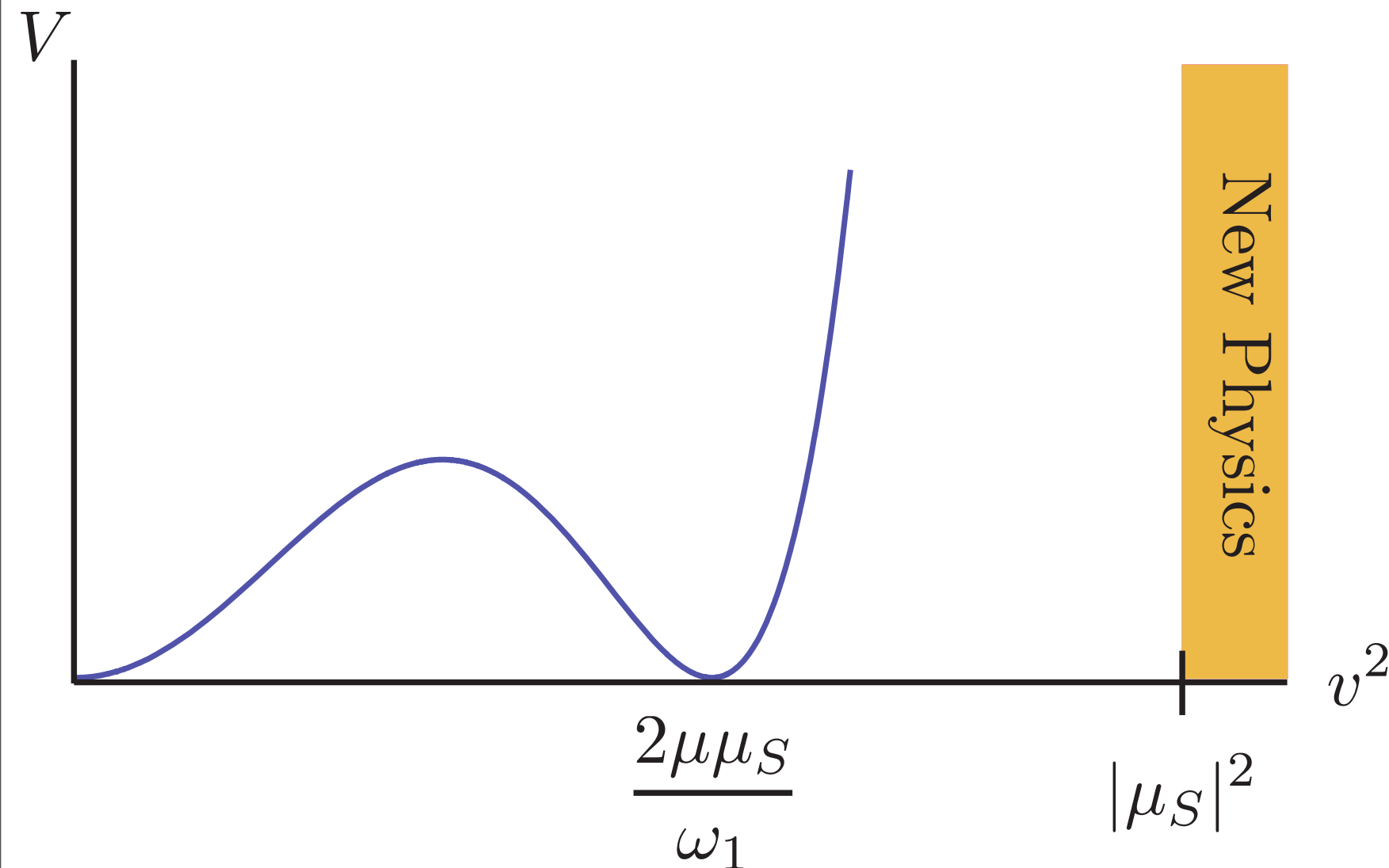
$$\rho \supset (H^0, A^0)$$

- m_ρ determined by the superpotential W,
  not g_w,
  much easier to find $m_\rho > 114 \text{ GeV}$

An effective field theory of sEWSB

$$W \supset \mu H_u H_d + \frac{\omega_1}{2\mu_S}(H_u H_d)^2$$

An effective field theory of sEWSB

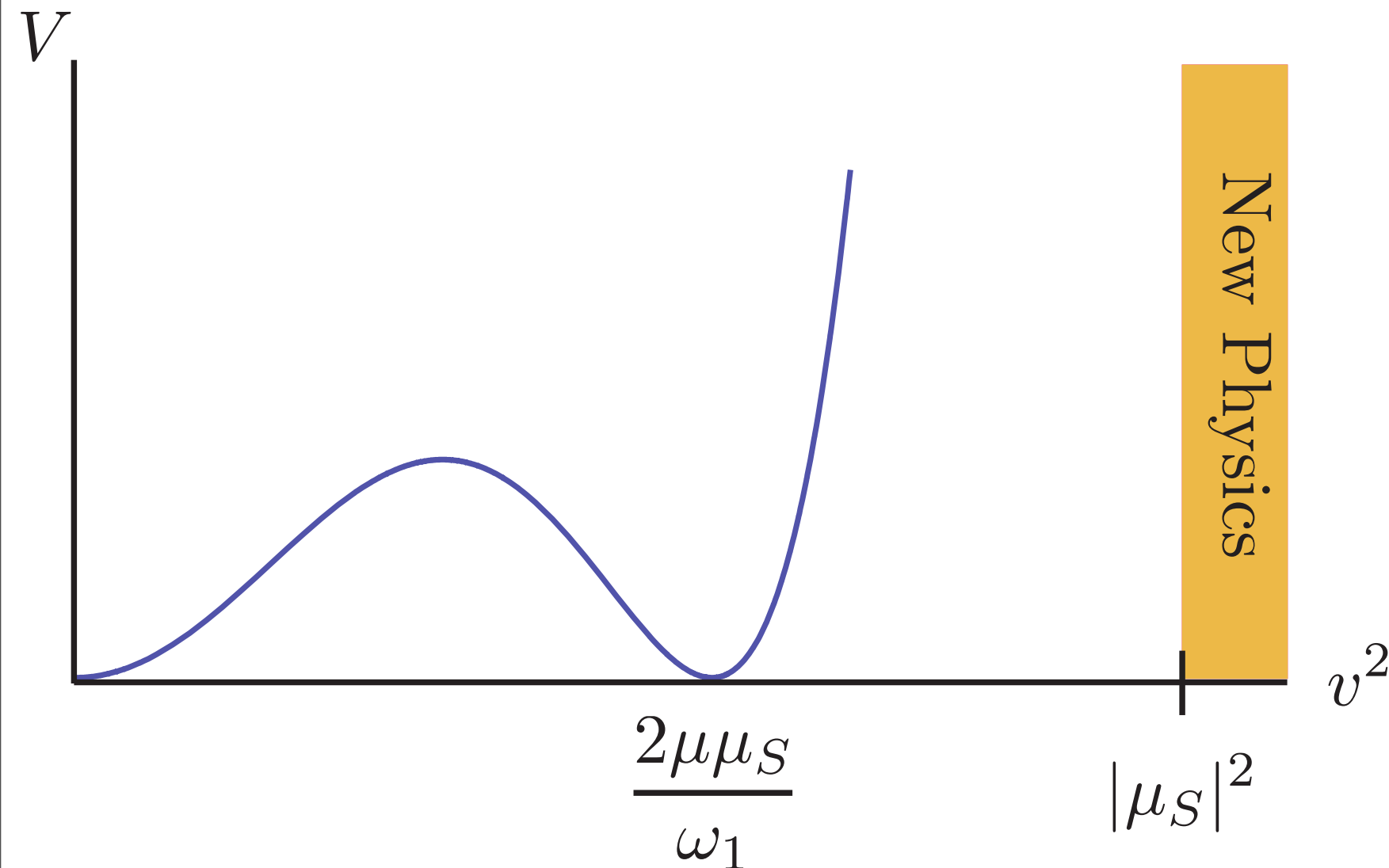$$W \supset \mu H_u H_d + \frac{\omega_1}{2\mu_S}(H_u H_d)^2$$

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$$m_\rho = 2\mu$$

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Corrections from higher-order operators

$$\sim \frac{v^2}{\mu_S^2} = \frac{1}{\omega}\frac{\mu}{\mu_S}$$

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Irony: under control only because there is no renormalizable tree-level quartic---
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- Some tension between making m_ρ large, but keeping the EFT under control.
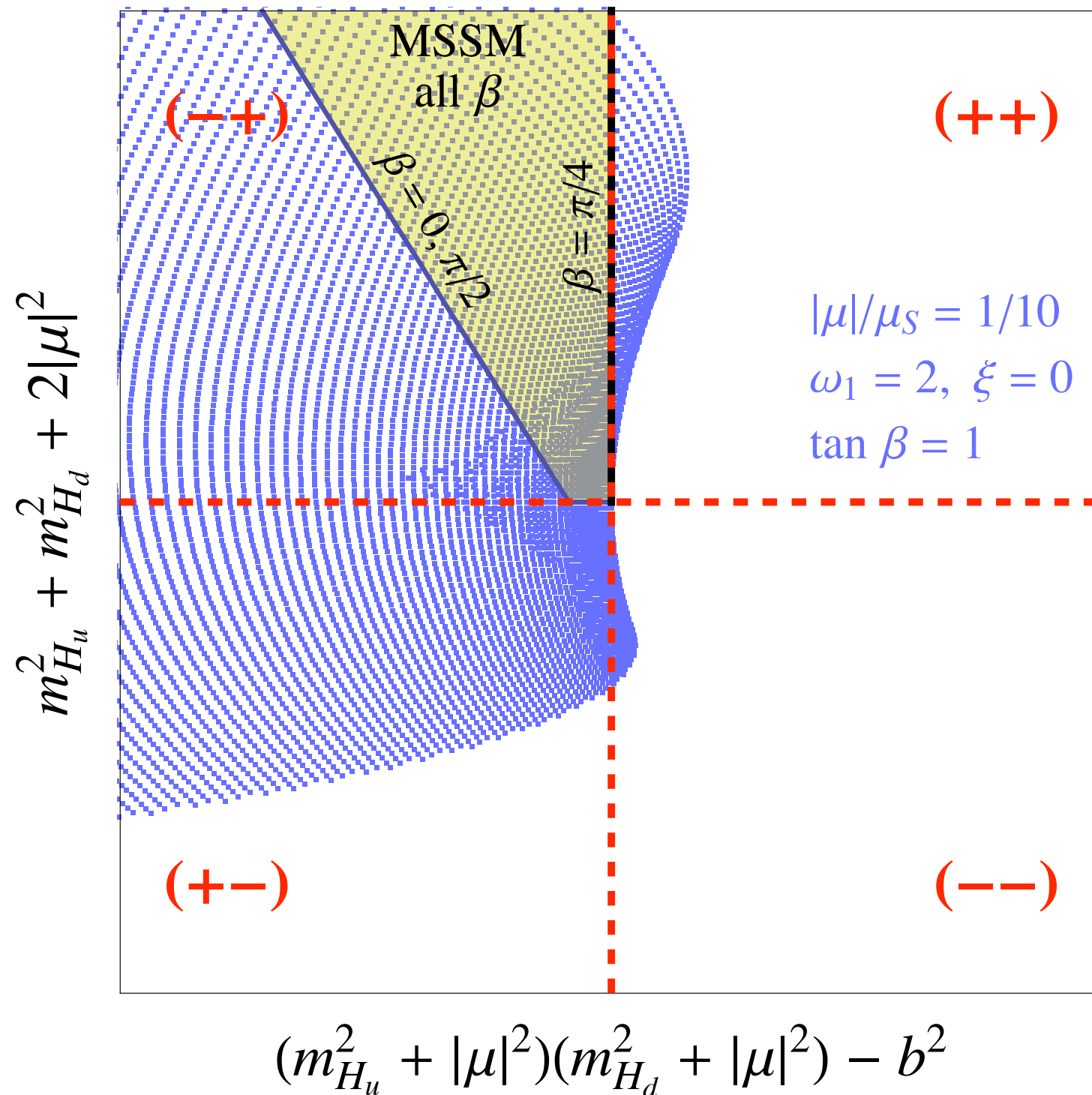
Inverted scalar hierarchy occurs when $2\mu > M_Z$

Turn on SUSY-breaking

- SUSY-breaking needed to lift the fermions

Mass	Scalars	Fermions	Vectors
0	—	1 majorana	A_μ
m_W	$H^\pm$	2 Dirac	$W_\mu^\pm$
m_Z	H	1 Dirac	Z_μ
$2|\mu|$	$h,\ A^0$	1 majorana	—

- Breaks the degeneracy with the origin

- Many terms, even without any new degrees of freedom

Much larger region of EWSB
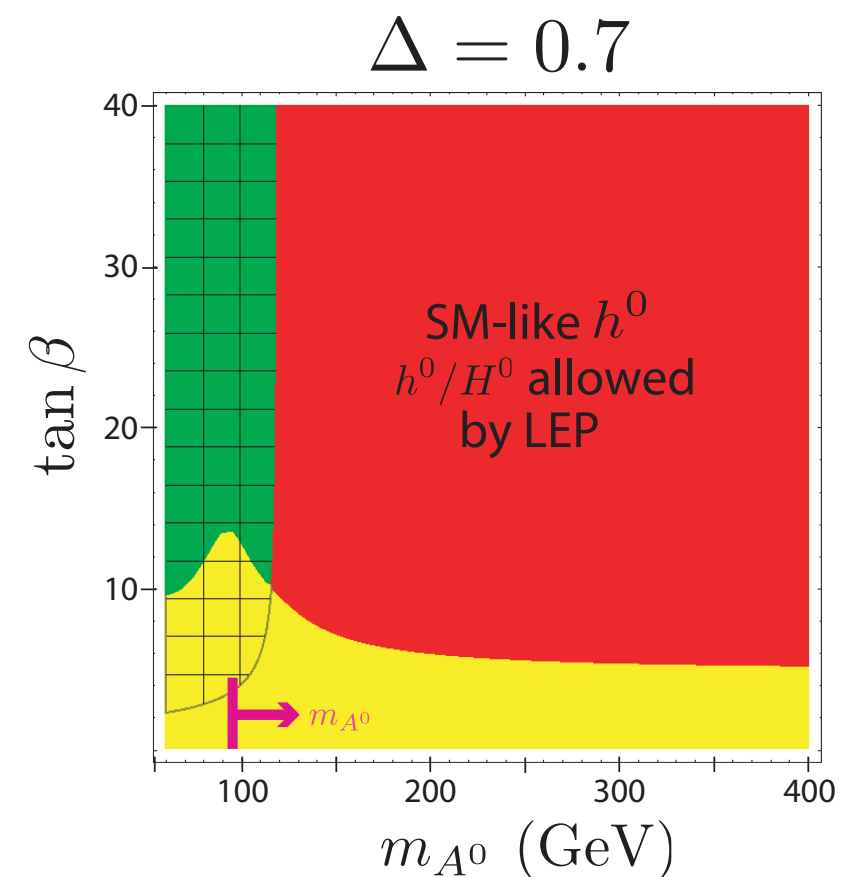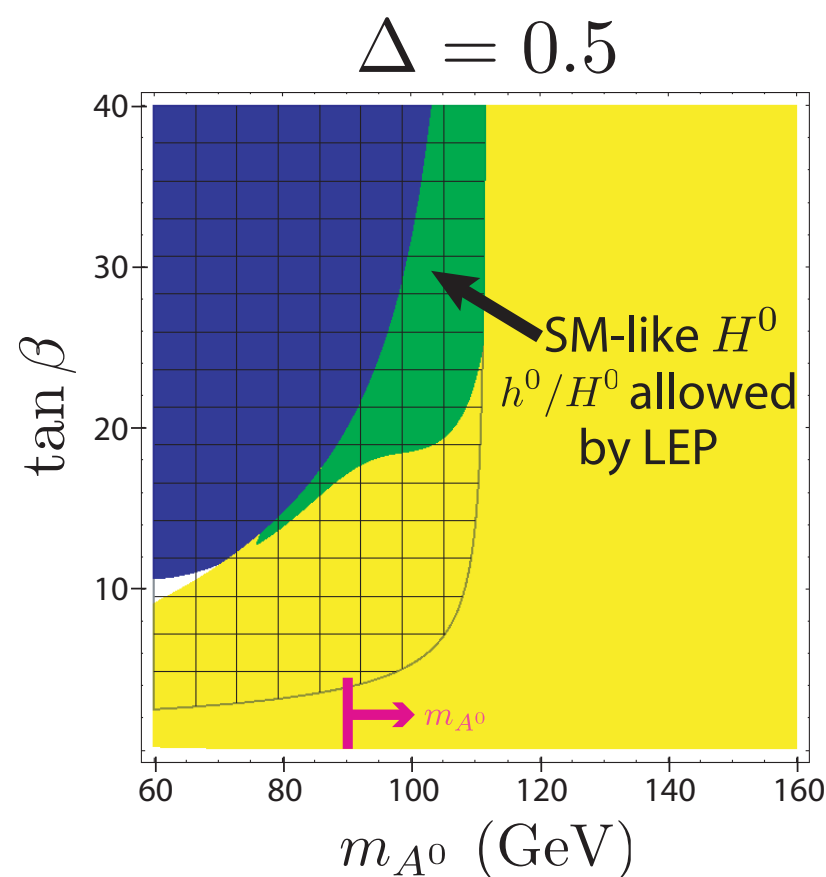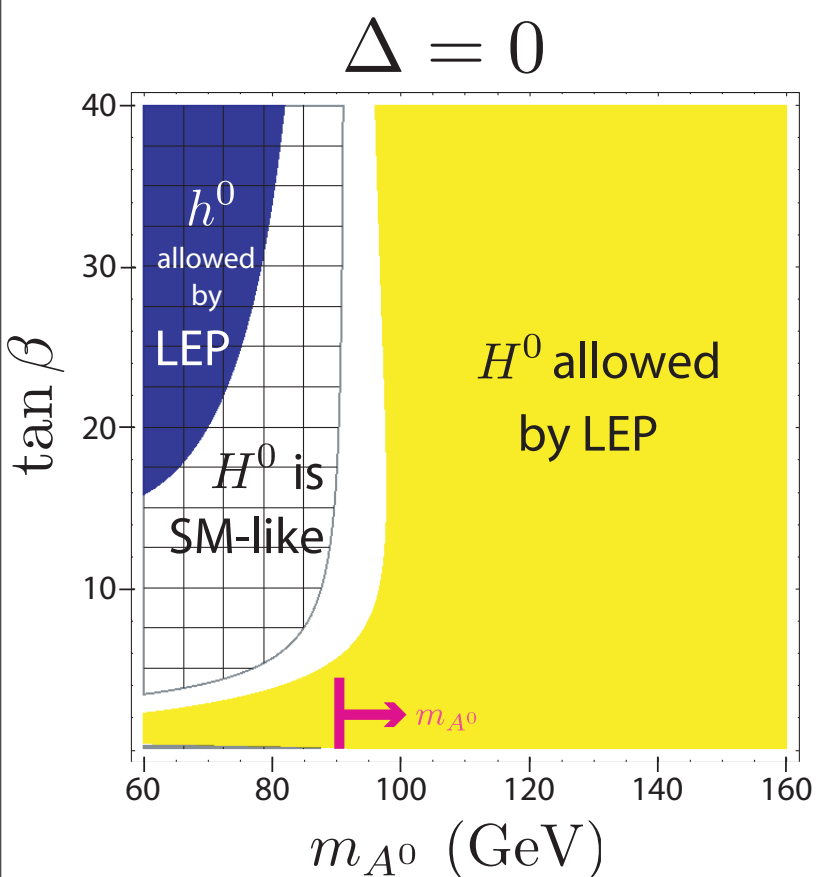

Generically, much larger region for EWSB

signs matter,
$$\beta \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$$
$$\tan(\beta) < 0!$$

Inverted Hierarchy in the MSSM

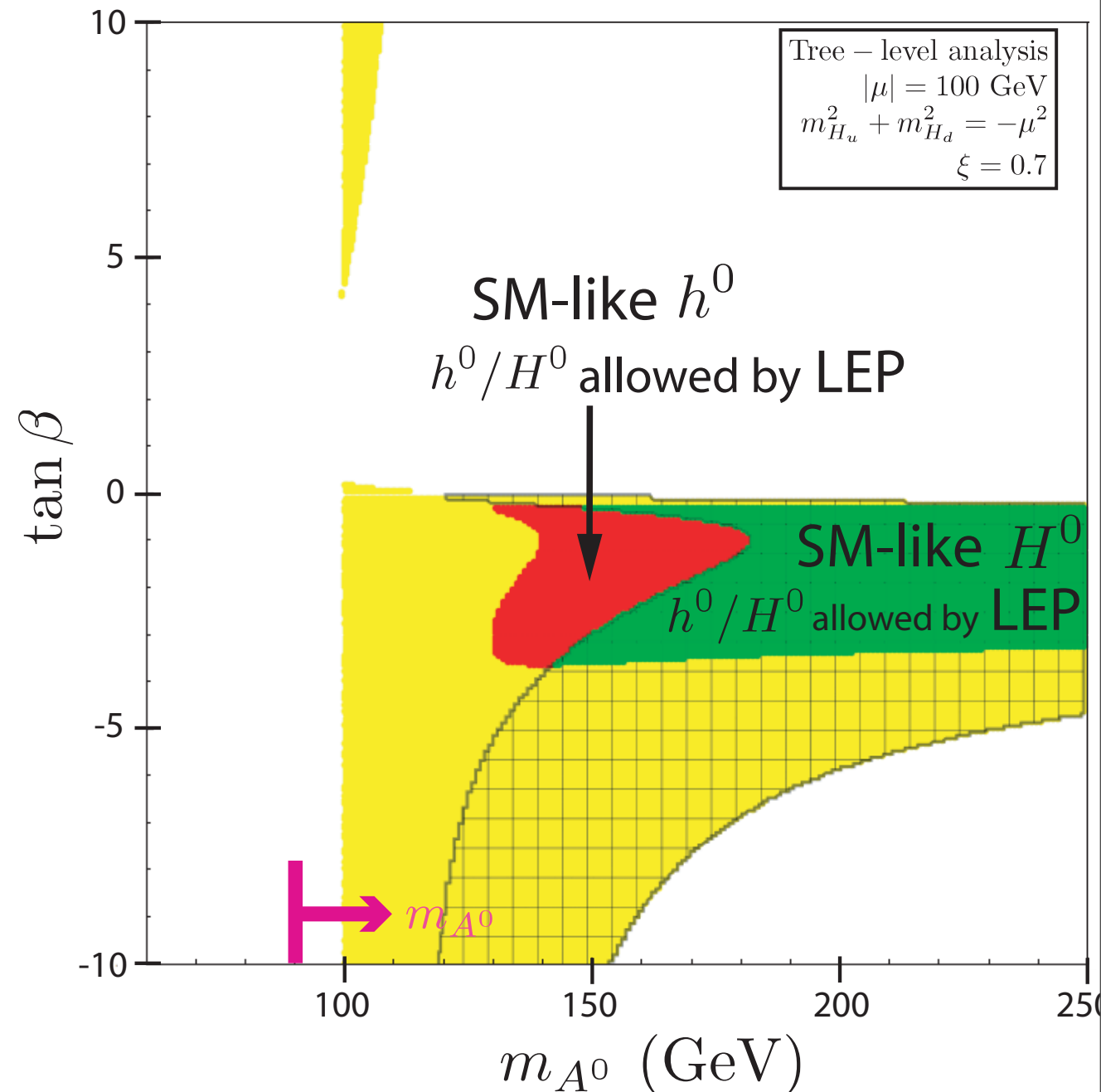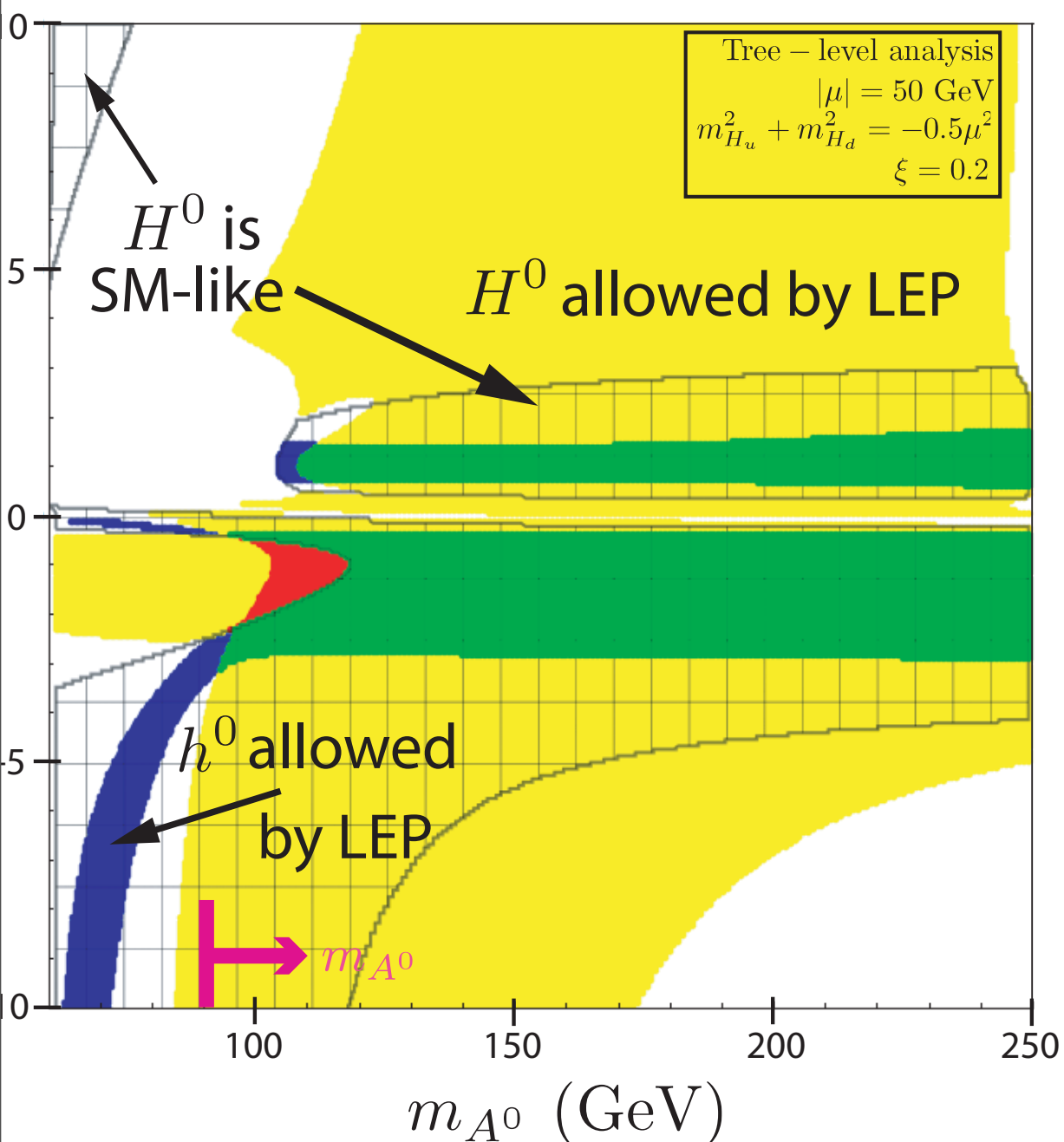- Inverted Hierarchy: H^0 is SM-like ($m_{h^0} < m_{H^0}$)

$$M_{\tilde{t}} \sim m_t \qquad M_{\tilde{t}} \sim 400 \text{ GeV} \qquad M_{\tilde{t}} \sim 600 \text{ GeV}$$

Must satisfy $m_A^2 \sim m_d^2 - m_u^2 - m_Z^2$ to a high degree
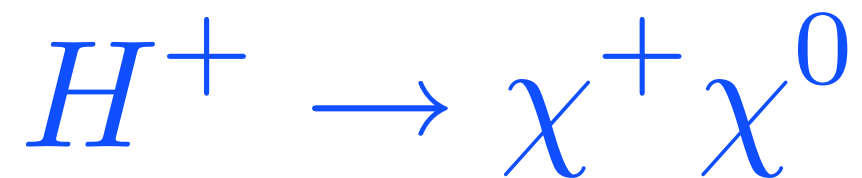
Inverted Hierarchy in sEWSB vacua

Inverted hierarchy in roughly 'half' of parameter space

Example Spectra

- Inverted Spectra are easy to find:

μ	ω	μ/μ_s	b/μ^2	m_u^2/μ^2	$m_{H_d}^2/\mu^2$	ξ	M_1/μ	M_2/μ
-150	2	0.14	-1.1	-0.99	-0.51	0.20	0.36	0.57

ρ	$\tan\beta$	m_{h^0}	m_{H^0}	$g_{H^0ZZ}^2/g_{h_{\mathrm{SM}}ZZ}^2$	m_{A^0}	m_{H^+}	m_{χ^+}	m_{χ^0}
.20	-1.3	190	210	0.77	185	190	105	60

$$H^+ \to \chi^+ \chi^0$$

- Chargino NLSP?

μ	ω	μ/μ_s	b/μ^2	m_u^2/μ^2	$m_{H_d}^2/\mu^2$	ξ	M_1/μ	M_2/μ
-70	1	0.11	-1.6	-1.7	.22	0.20	1.5	1.7

ρ	$\tan\beta$	m_{h^0}	m_{H^0}	$g_{H^0ZZ}^2/g_{h_{\mathrm{SM}}ZZ}^2$	m_{A^0}	m_{H^+}	m_{χ^+}	m_{χ^0}
0.34	-1.8	120	140	0.82	110	125	100	110

Conclusions

- Post-LEP, it is worth reconsidering what the most likely BSM Higgs sector looks like:

$$h^0 \to 2a \to 4b \qquad m_{h^0} < m_{H^0}, H^0 \text{ SM-like}$$

- Supersymmetric EWSB is a qualitatively new starting point---EFT approach is very powerful!

Easy to UV complete into a theory with $W \supset \lambda S H_u H_d$

- Light Higgs -> Light charginos, charged Higgs + new phenomenology!

Rich Vacuum Structure---cosmological applications?

- supplements

Decoupling of sEWSB vacuum